Gaston.

Electrical Equipments For Movable Bridges.

ELECTRICAL EQUIPMENTS

FOR

MOVABLE BRIDGES

BY

RALPH MAYO GASTON

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THESIS

SUBMITTED IN PARTIAL FULFILLMENT
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DEGREE OF
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I HEREBY RECOMMEND THAT THE THESIS PREPARED BY

Ralph Mayo Gaston

ENTITLED Electrical Equipments for Movable Bridges

BE ACCEPTED AS FULFILLING THIS PART ON THE REQUIREMENTS FOR THE

PROFESSIONAL DEGREE OF Electrical Engineer

Head of Department of Ellery B. Paine.

Recommendation concurred in:

C. R. Richards
Edward C. Schmidt

Committee

P R E F A C E

When the writer began to work on electrical equipments for movable bridges, the designers did not understand the operating characteristics sufficiently well to get results in the easiest way. As a rule the machinery was designed by structural engineers who had little sympathy for either mechanical or electrical details. Failure to consult the electrical engineer often resulted in more severe service being imposed on the electrical equipment than would otherwise be necessary. One example of this was the practice which existed for several years of mounting the motors of bascule bridges on the moving leaf. The turning over of the motor frame as the bridge opened made complications in the bearing lubrication. It seems queer that capable structural engineers would permit a poor grade of work on such an important part of a high grade structure.

Mr. Bryon B. Carter, who had charge of the machinery design for the Rock Island bridge, was an exception to the above, as he is a graduate in mechanical engineering from the University of Wisconsin. Mr. Carter did considerable mechanical work for Mr. Ralph Modjeski, and did it far better than most of the structural engineers who design the other portions of drawbridges could have done it.

Even in 1903 reliable methods of estimating motor sizes for bridge equipments were understood by very few, and satisfactory specifications had not been written. It is still

almost impossible to write specifications which will insure high grade work by inexperienced forces, and besides, detailed specifications often become obsolete before they are executed.

Quite frequently structural engineers have submitted designs and specifications for criticism before asking for bids. This places an engineer in a very peculiar position as he does not know whether he is preparing specifications for his own guidance or that of his competitor. Several times paragraphs prepared in this way have looked much different when one followed them for the construction of contract work. The designs for the Interstate Bridge at New Duluth for the United States Steel Corporation were handled in this manner, and the writer suggested the unusual location of the operator's house, which was adopted.

Nearly all railroad bridges are built without interruption of traffic, and even put into commission with only a few hours' delay. Each individual bridge embodies many new and untried conditions, which must be met successfully with few chances for preliminary experiments. Such a schedule requires a type of engineering, which is seldom required in other branches of work where repeated duplication overcomes faults as they appear in earlier attempts.

Regardless of the serious consequences which may result from the failure of a bridge equipment, the appropriation for the electrical work is often too low to permit first-class work or sufficient duplication of important units. This class of work is frequently let by contract and the lowest bidder is expected to provide the best equipment.

No attempt has been made to describe all existing installations, but only sufficient of them to show the main steps in the development of important details. The writer has had intimate connection with all of the equipments referred to in this way.

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I. WHY ELECTRICAL EQUIPMENTS ARE REQUIRED

Some form of movable bridge is required at nearly all points where railroads and highways cross navigable rivers and canals. The only exceptions are where the railroads or highways cross at such high levels that the water traffic can pass under without interference with the bridge. The vertical clearance above the water line required by the boats varies from a few feet in the case of small canal boats to 125 feet or more where the waterway is used by large lake or ocean boats.

The United States War Department, which controls most of our waterways, permits bridges to be erected and used only so long as usual regulations are followed. This department rules that the water traffic has the right of way in preference to either highway or railroad traffic. This means that the bridge may be used if water traffic is not materially inconvenienced. Fines are assessed the bridge owners if boat traffic is seriously delayed.

Reliable operation of the movable bridges is very important to the railroads which depend on them. Possible failure of a movable bridge to operate when required is so serious that the railroads often install emergency gasoline sets of some kind

to be available, if the regular power equipment should fail. Expensive storage batteries are sometimes used to insure a reserve energy storage close at hand.

Many of the early movable bridges were operated by hand or steam and later gasoline was used. The increasing size of boats has required the waterways to be made wider, thus making the bridges longer. The increasing weight of trains and street cars has caused the bridges to be made heavier. These two changes have developed bridges so large that hand operation is not very popular; at least it is impracticable where frequent openings are required.

Steam operated bridges are not economical where the bridge movements are infrequent; because steam pressure must be maintained between swings which wastes coal. The operators' houses are often so located that it is not convenient to transport coal to them. Large bridges often require that power be applied at several widely separated points. When steam engines are used they can not be so conveniently located close to the work as electric motors. When steam boilers are used in cities they must conform with local ordinances and only licensed engineers be employed as bridge tenders.

The use of gas engines is subject to many of the same inconveniences that are experienced in using steam engines. The gas engine is even more troublesome on account of not being reversible and not being able to start under load. When direct mechanical drive is used, clutch and reverse gears are necessary so the resulting combination is not convenient to handle in

restricted space. Gasoline and oil engines are very satisfactory when used to drive generators which in turn either charge storage batteries or furnish current directly to the operating motors.

Electrical operation is very much to be preferred because the motors are so compact, considering their output. The motors may be placed close to the work to be performed and are readily controlled by the operator; even though they are a considerable distance away from his position. When electrical equipments are used, electricity is available for lighting and indicating, which is quite a convenience. Electrical equipments can be readily protected by interlocking of the various machinery sets.

II. GENERAL DEVELOPMENT OF BRIDGE EQUIPMENTS

The first bridge to be operated by electrical motors in this vicinity was the Rush Street Bridge in Chicago in 1890. This bridge was formerly operated by a steam engine and the motors were substituted when the steam equipment needed extensive repairs. Mr. George P. Nichols, then with the old Thomson-Houston Company, sold the motors and thereby became interested in electrical equipments for bridges.

In 1894 Mr. George P. Nichols, who had left the Thomson-Houston Company and formed a partnership with his brother, Mr. Samuel F. Nichols, equipped the Scherzer bascule bridge over the Chicago River at Van Buren Street, Chicago. This bridge was equipped with railway motors and was wired with lead covered cable without pipes or conduits. The insulation of the motors at first suffered from moisture, but the motors have given good service since. Immediately after this was completed, they secured an order for equipping the Columbus Street Bridge in Cleveland. This bridge was a double span swing bridge which is quite an unusual type. Each span was operated by a Westinghouse 12-A, railway motor which was wired with lead covered wire run in common iron pipe. Factory bent elbows were not on the market at that time, so elbows were made of closely coiled wire springs slipped over the pipe ends.

During the next succeeding years a number of moderate sized bridges were equipped. The first really large electrically operated bridge is located at Rock Island and is a combi-

nation railroad and highway swing span. This bridge is still in use and is over 365 feet long and weighs about 2,400,000 lbs. It is swung by a 50 h.p. motor and the end lifts and rail locks are operated by compressed air.

The controllers, switchboards and miscellaneous details of these original equipments would be called crude today; still many of these devices were very successful.

The equipments for large bridges gradually became more and more extensive as the convenience of electrical operation proved its worth. The large swing bridges were provided with machinery for lifting the ends after they were closed. This procedure is necessary in order to avoid excessive stress in the chords when loaded. Disc center bridges even require wedges at the center to prevent any tendency to overturn. If the bridge is used by trains or street cars, the rails may be locked mechanically. If a bridge is moved by motors, these minor operations can also be best operated by motors.

The first important bridge work done by the writer was on a 520 foot swing span over the Missouri River at Omaha for the Illinois Central Railroad. The Consulting Engineers furnished plans and specifications covering interlocking equipment which interlocked the control levers, but not the positions of machinery sets themselves. A preliminary wiring diagram for a complete electric interlocking system was presented to the Consulting Engineers, who accepted it in preference to the original design.

This bridge was supplied with 500 volt direct current by means of an overhead line feeding through a system of collector rings mounted around the swiveled wire pole at the top of the bridge. The span was swung by two thirty horse-power railway motors, and the ends were lifted by means of two wedges at each end driven by motors. The rail locks were operated by compressed air furnished by a motor-driven compressor in the operator's house.

A second swing span was equipped at Omaha in 1906, which made an unusual arrangement of two 520 foot spans, end to end. This was necessary on account of the shifting tendency of the Missouri River at this point.

The second Omaha installation utilized for the first time the arrangement of two independent end lift motors starting simultaneously from one resistance. This arrangement feeds them current at the same voltage regardless of load balance and tends to make them operate together. This gave much better results than separate starting resistances, and has since been used with even three motors.

The circuit breakers protecting the end lift motors were provided with shunt trip coils which were used to open the motor circuits at the ends of the machinery travel. Switches connected to the machinery closed the circuits at the proper time for making the stop. The fault with this scheme was that poor contacts in the switches and breaks in the wiring were not observed till after the machinery had overrun.

A great amount of care is necessary in selecting the electrical equipment for a movable bridge, because the requirements cover such an extreme range. The motors operating the bridge leaf must have very sensitive control in order to permit the operator to stop within a fraction of an inch of the closed position. The lock motors may be started with almost full voltage where the masses to be moved are small. Stock resistances can not be expected to give satisfaction for such a range of service. The electrical manufacturing companies furnish resistances which will prevent injury to the motors, but they frequently fail to give proper consideration to the machine to be operated. They fail to provide both sensitive control and ability to accelerate quickly enough under heavy load conditions. The write has found it necessary from the first to give each resistance layout personal attention.

Drum type controllers for motors above seventy-five horse-power capacity become quite clumsy, so the contactor type with small master switches are frequently used. In this way the operator can be located in a convenient place for observing the river and bridge traffic while the control apparatus may be located some distance from him if desired.

The use of storage batteries in connection with bridge equipments greatly increases the cost of the equipment, but it is justified in many cases. Ordinarily, a bridge is only operating a few minutes a day, although it may demand a very heavy

current at times. This type of load is not desired by the power companies which will usually fix a high connection charge. The use of a storage battery charged eight to twelve hours a day at a low rate will sometimes reduce the connection charge nearly enough to pay interest on the storage battery investment. The storage battery also insures against failure of power caused by line troubles as the battery would be able to supply the bridge for several hours. Where an isolated plant is used, it can be run only a few hours a day and the battery will operate the lights and the bridge whenever required.

III. SELECTION AND APPLICATION OF MOTORS

When motors are selected for a new bridge, there is no chance to make tests to determine the correct sizes to use. This means that the work the motors have to perform must be estimated from drawings of the bridge. The cycles of operation must be predetermined by giving proper consideration to friction, wind resistance inertia as well as loads to be lifted. The cycles of operation are usually short and infrequent, which makes the heating of the motor on an hour or a half hour basis unimportant. The heaviest loads are usually at moment of starting or in other words, if a motor is able to start the extreme load, it will be able to move it fast enough for emergency conditions.

The movable bridge spans are usually about balanced so there is never a great amount of load to lift. There are several types of bridges, which differ materially so the friction and wind resistance will depend on the type as well as the workmanship and condition of lubrication. The methods used in estimating the friction and wind resistance of the more common types are given below for illustration.

Swing bridges, as shown by diagram 1 are supported by disc centers or nests of rollers. If a disc center is used, the friction is proportional to the rate of travel of the central pressure point. If the bridge rests on rollers, the power is proportional to the rate of travel at the center of

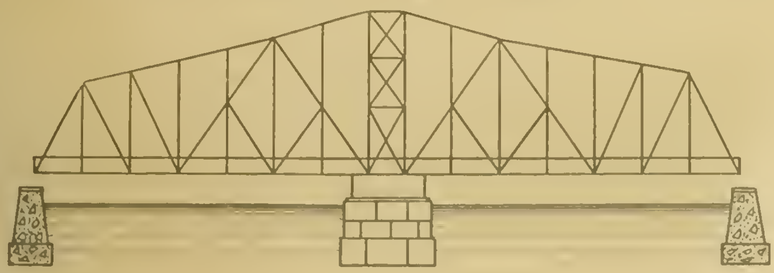

DIAGRAM-1
SWING SPAN

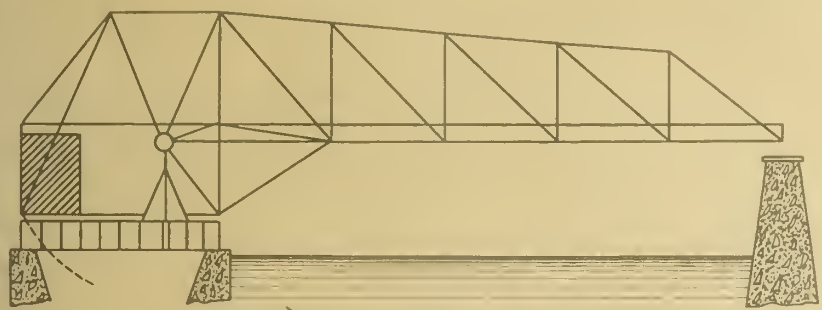

DIAGRAM-2
PLAIN
TRUNION BASCULE

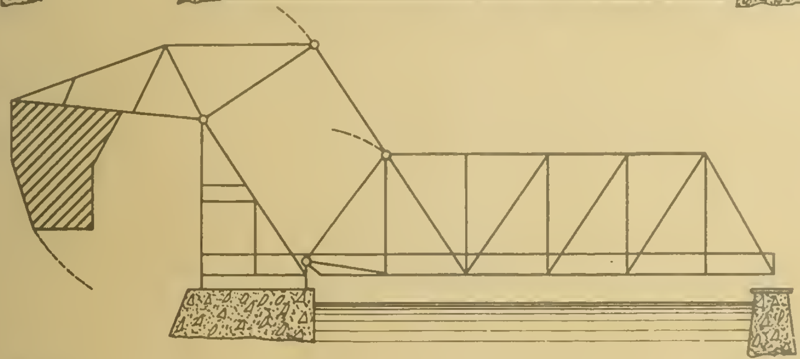

DIAGRAM-3
STRAUSS
TRUNION BASCULE

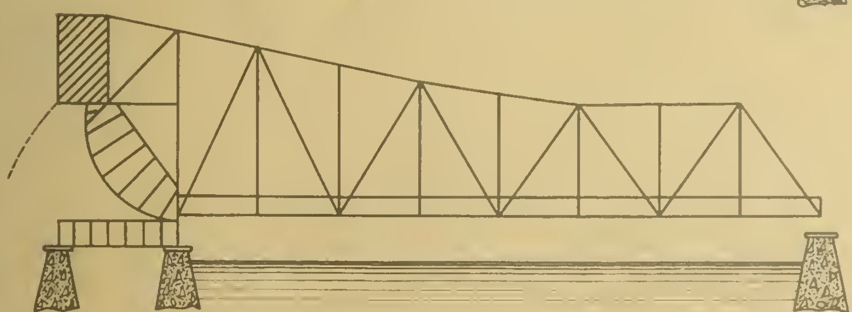

DIAGRAM-4
SCHERZER
BASCULE

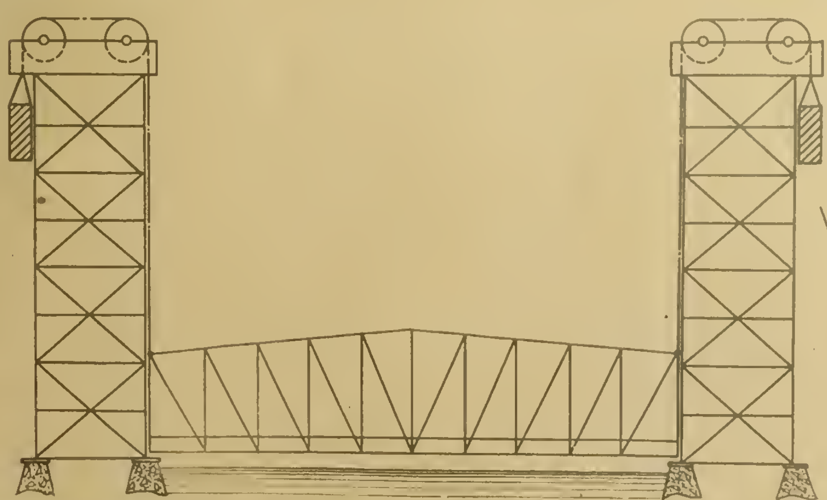

DIAGRAM-5
WADDELL
&
HARRINGTON
VERTICAL LIFT SPAN

BRIDGE
TYPES

the roller track. The wind may press against one arm more than the other so it is customary to allow from two to five pounds per square foot of exposed surface over the full length of the bridge as wind resistance.

The friction of a plain trunion bascule bridge as shown by diagram 2 is proportional to the load and rate of movement at the surface of the trunion bearing. It is readily seen that the entire weight of the bridge and counterweight is carried directly on the trunions and in normal operation moves eighty degrees to open. The leaf when raised, receives the full force of the wind. Motors are usually selected to operate against seven to fifteen pounds per square foot of floor surface and only a small allowance is made for the open spaces between ties of a railroad bridge.

The friction of a Strauss trunion bridge as shown by diagram 3 is only slightly greater owing to the friction of the link connections. The friction of the main trunion and counterweight trunion varies at different points due to shifting of the loads during operation.

The friction of the Scherzer type of bascule as shown by diagram 4 is that of a large segment rolling on a level track and would be very low if it were not for the teeth, which are necessary to keep the segments in proper relation to the supporting track; dirt and rust on the track produce additional friction. The wind load on a Scherzer type of bascule, when open, is greater than the wind load on a corresponding length

of trunion bascule. As the bridge starts to open, it rolls up onto the segmental girder and raises the span higher up into the air by a distance equal to the radius of the segment.

The friction of a Waddell & Harrington type of vertical lift bridge as shown by diagram 5 is proportional to the weight carried by the sheave axles and the rate of travel of the trunion surfaces. In practice the load is supported by two sets of sheaves and they turn two to three revolutions in raising the span to clear a boat. Vertical lift bridges are not affected by wind loads sufficiently to alter the motor calculations.

The wind pressures referred to may seem low when compared to pressures used in estimating wind stresses in stationary structures. This is accounted for by the fact that boats can not navigate rivers and canals during hard wind storms, so there is no necessity for operating bridges during high winds.

Motors shall be so selected and geared that they can safely operate under adverse conditions of wind and excessive friction, but they should be geared to give a desirable rate of operation under normal conditions.

The selection of gear ratio should be left to the electrical engineer so as to obtain ratios which are favorable to the motors and to secure results with as low current consumption as possible. The economy of current is important when charges are adjusted on a maximum demand basis or current is supplied by a private storage battery. If a series motor is used to perform a certain amount of work in a definite time, it

will operate a certain average speed, depending on the load. The average speed should be used in determining the gear ratio without any regard to the rated speed of the motor. The cycle of operation should be examined to see that the motor is sufficiently loaded at all times to prevent dangerously high speeds. The slip-ring motor is almost a constant speed motor so the question of gear ratio selection is an easy matter.

Quick acceleration of a bridge to dodge boats is important and should be given careful consideration. If a river has a swift current, large boats are hard to manage so the operator must ust skill in clearing the bridge of traffic in time to avoid a collision.

The sizes of motors for bridge equipments are selected almost entirely by the horse-power or torque they can develop momentarily; because a motor able to satisfy this condition safely is large enough to keep cool for the short cycles of operation required.

Originally considerable difficulty was experienced in getting the manufacturers to state what maximum starting torque their motors could be depended upon to develop. Finally, to settle the difficulty, arrangement was made for the writer to supervise some tests on stock series motors and the designers were very much surprised to see them develop over six times normal torque without any sign of distress. After the start had been made the factory continued the tests to cover all the sizes, and furnished a schedule of maximum safe torques with the nec-

essary currents. The maximum torques in some cases ran as high as ten times the normal torques. The line of motors referred to was made with cast steel frames of compact form and was originally designed for crane duty. Commutating poles were not used and brushes were set on mechanical neutral. In actual practice it is not safe to develop such torques with small pinions because the shafts might fail on account of the bending moment. However, this class of motors can be depended on to develop four times full load torque in service.

Slip ring motors can be built to develop very high starting torques, but as they would not stand as much abuse as a direct-current series motor, the manufacturers refuse to make them as regular production. The ordinary high torque motors will develop a starting torque about two and one-half times normal running torque under test room conditions and about two times under best service conditions.

Assuming that a series motor can be depended on to develop four times its normal torque, it is apparent that the rated capacity of an induction motor on an hour basis will be higher than the rated capacity of a series motor to do the same work. Applications which require a motor selected almost entirely by its momentary capacity are so rare that it seems queer to consider a fifty horse-power series motor to be interchangeable with a hundred horse-power induction motor. The writer has found from tests on a large number of installations that this method of selection of sizes will give as near equiv-

alent results as can be expected from motors of the different types.

Motors insulated with dry cotton insulation are not suitable for use on bridges on account of the damp surroundings. Some companies have sent out a great many machines made up in this way, but sprayed or painted on the outside of the coils so that their real construction is not revealed by an outward inspection. Such machines are liable to be injured by moisture collected inside of the frames by condensation, especially if they are of the enclosed type. Motors for this class of work should have all windings twice dipped in proper varnish and baked, or better still, have coils completely impregnated by a thoro process.

IV. METHODS OF STOPPING AND HOLDING MACHINERY

The exacting conditions imposed on bridge equipments often make the brake systems nearly as important as the propelling equipment. Bascule bridges which expose large areas to the wind require reliable brake systems to stop and hold against wind loads. Some types of bridges have unbalanced conditions which demand brake systems as reliable as those used on trains.

The machinery sets which handle heavy balanced bridges are never strong enough to make sudden stops, so care should be used to avoid dangerously high stresses.

Many types of brakes have been used, but mechanical brakes operated by hand levers or hand wheels are very satisfactory if the connections are fairly direct and the bridge not too heavy. Hand brakes operated by one man must be efficient to be successful, as the power he can exert is rather limited. In the case of bascule bridges having the motors and machinery on the moving part it is very difficult to design satisfactory lever connections for hand brakes, so other types have been developed.

Air brakes are frequently used but are not entirely satisfactory when flexible connections are necessary to reach the machinery. They usually require the installation of a motor-driven compressor and storage tanks involving considerable expense.

Solenoid brakes have frequently been used, but are not entirely satisfactory for all purposes as there is no possibility of adjusting the retarding torque in a convenient manner while operating. They must be all on or all off without any intermediate positions. If they are adjusted to develop sufficient retardation for emergency conditions, they cause too much wear and strain on the machinery for frequent operation. Solenoid brakes on the main machinery sets are shunt wound to permit the release to be maintained after the current has been shut off of the motors; thereby allowing the bridge to coast. It is dangerous to leave current turned on shunt brakes more than half an hour at a time; hence the switches are opened with springs.

The lack of adjustment of solenoid brakes has encouraged the use of two brakes on the same machinery set, so one or both may be used as required.

Large solenoids are so slow in operation that they interfere with the operation of the bridge. The solenoid core moves after the switch is opened or closed and as the size of solenoid increases the lag may reach several seconds, so other types of brakes must be used. Large solenoid brakes cause trouble on account of the long momentary arc which is produced when current is shut off. They even reach over a foot in length when not suppressed by artificial means.

The writer has made rather careful comparison of work output of direct-current solenoids having flat pole tips and

conical pole tips. The conical pole tips increase both the pull and useful travel when the air gap is in the center of the solenoid. The useful work is doubled.

Brakes operated by motors have a wide range of application. Such brakes, like solenoid brakes, are set and held by springs. The motors compress the springs and thereby hold the brakes in release only so long as current is turned on them. Brakes of this type will give any desired degree of retarding torque as a small current through the motors will oppose the setting spring without releasing it. The results are far better than can be obtained from solenoids. Using a motor in this way is unusual, as it makes only a few turns and comes to a stop as the spring is compressed, while still carrying current. The motor and the resistance used in series with it are both selected to withstand connection to the line continuously without injury.

Motor brakes which are released by series solenoids are used on all direct-current lock machinery sets, in conjunction with the automatic stops. Alternating-current solenoids are always connected in shunt, as the impedance is too great to permit series connection.

The various locking sets for operating the rail locks, end locks and rear locks have only small inertia so the main work that the brake has to do is to stop the motor armature. For this purpose the brakes should be very powerful so as to reduce the coasting to a minimum. With strong brakes and auto-

matic stop switches on the machinery sets, an operator can handle such operations very rapidly. The time allowed for complete operations of this kind is from five to twenty-five seconds.

The wearing surfaces on early brakes were wood shoes against cast iron wheels. Later cast-iron shoes were used with oil and cast-iron shoes with babbitt inserts which required less oil. The wear on some of the wood and metal shoes was quite rapid and required considerable care to maintain the adjustment; so automatic take-ups were used. These consist of a ratchet on the adjusting screw operated by the movement of the brake before the plunger travel exceeded a safe limit. Recent brakes use asbestos webbing or asbestos blocks against iron. This material can be used with either flange or disc brakes and is so durable that it requires little attention in service.

STOPPING WITHOUT THE USE OF BRAKES

The consulting engineer for the Vancouver Bridge was so prejudiced against solenoid brakes that he would not permit their use on the end lift motors. Slip-ring motors which were used on this bridge could not be readily adapted to dynamic braking, so the motor leads were reversed and resistance inserted by means of the stop switch. At the instant the motors came to rest, the line connections were broken by centrifugal switches to prevent reversal of the motors.

In order to avoid the use of solenoid brakes, various combinations of dynamic braking have been applied. When a dynamic brake is so arranged as to depend on self excitation, it will not always begin to generate instantly, probably owing to variations of contact resistance which is considerable when operation is infrequent. On the other hand, if line excitation is used the line supply might be cut off at a critical time and interfere with the stop. After several attempts, dynamic braking, used alone, was abandoned for future installations.

Some lock machinery sets are so designed that they are liable to breakage, if the motors travel beyond the usual stopping points. As the motors operating these sets are usually stopped automatically, it is very important that the stopping process will be reliable at all times. The wires which open the motor circuit when the stop is made might become deranged, and fail to stop the motor at the proper time; hence it is desirable to have some other method of stopping the motor and prevent machinery breakage.

When slip-ring motors are used, the stator leads can be reversed when the stop switch reaches the proper position; and thereby give the armature a stopping impulse before the overload relay can work. If series motors are used, the armature can be short-circuited which causes a heavy rush of cur- through the field and generates a reverse armature current, causing an abrupt stop by the time the overload devices can disconnect the line. These arrangements seem severe on the

motors, but the writer has never heard of any injury being caused to any of the electrical equipment in operation.

V. PROTECTION OF LIFE AND EQUIPMENT BY INTERLOCKING

All traffic railroad or highway, which passes over movable bridges, should be protected while the spans are open. In case of railroad bridges the danger signals and derails should be locked in proper position before the bridge should be allowed to open. It should be impossible to 'clear' these safety devices before the span is again closed and ready for traffic. In order to accomplish this the railroad signal system must be extended to the bridge or interconnected with a proper interlocking system on the bridge.

In case of highway bridges, the traffic should be warned by bells, red lights and warning gates. There has been a recent tendency to obstruct the roadway with a substantial barrier while the bridge is open. Whatever devices are used, the operator should be unable to open the bridge until they are properly set, nor should he be able to remove the warnings while the span is open.

In the operation of every large bridge there is only one safe order for the movement of the various machinery sets. The original method of interlocking, such as used on the Rock Island Bridge and suggested for the first Omaha bridge, only interlocked the operating handles without any definite regard to the motions themselves.

The interlocking scheme uséd on the first Omaha bridge utilized a master drum which made one complete revolu-

tion for a cycle of operation. This drum could be advanced but a notch at a time, where it was stopped until the function at that position had been completed. Each machinery set operated a switch which released the master drum with a solenoid as soon as the machinery travel was completed. All later interlocking systems designed by the writer dispensed with the master drum. At first, circuit breakers were used having either low voltage coils or shunt trip coils which prevented them from latching in the closed position until the proper time. When using these the operator performed one operation and then closed the circuit breaker by hand for the next operation. As soon as the mill-type contactors, or solenoid-operated switches, were available they were used so as to save the operator's time while operating. These switches require an ampere or less which can be conveniently handled on all the interlocking switches.

Slight irregularities in operation might cause serious and expensive delays if the interlocking system was entirely inflexible. This situation has been relieved by the use of emergency switches which will nullify the interlocking system either in sections or entire. These release switches should be operated only in extreme emergency and only when the operator is doubly sure no harm would be caused by their use. It is customary to mount these switches in a sealed glass case so the bridge maintainer can insist on explanations whenever they have been used. The two leaves of the Lake Street Bridge over the Chicago River are interlocked with each other and the

Elevated Railroad signal system through submarine cables. In case a submarine cable should fail or be pulled out by a boat anchor, the emergency switches will disconnect the cables and supply current for the control circuits through reserve fuses.

The Lake Street Bridge is the first highway bridge in Chicago to be protected by an interlocking system. This protection insures the roadway gates to be closed, a sign flasher to flash red warning light across the highway and a warning gong to give a sound warning. Accidents would not be caused so frequently by open bridges if this practice were universal.

VI. ELECTRICAL INDICATORS

Electrical indicators are used in several ways and form quite an important part of the equipment. The movable span or leaf may operate a switch which controls lamps in the operating house and thereby provides an indicator for the operator which shows the position of the bridge at all times. The indications may be controlled by two or more switches so located as to give very exact positions at certain parts of the motion. The closed position of a bascule or vertical lift span should be indicated so the operator will know when it is safe to operate the locks which may permit of a variation of only one-eighth of an inch in the position of the end of the span. An indicator of this kind is desirable in the day time and very necessary for convenient operation at night. Several spans may be operated by one operator and some of them may be quite distant, but with a carefully arranged light system, operation can be made convenient.

It is customary to arrange lamp indicators for all lock sets and for signals between the operators if more than one operator is concerned with the bridge. The connections are so arranged that the lamp indicates when the interlocking will permit the succeeding motion to start.

When several indicator lamps are mounted near the operator, it is quite important to enclose them in a box. This is necessary as night operating must be done in a dark room so

that the operator can readily see the boat lights. The blinding effect is removed by the use of colored glass lenses mounted in the top of the box.

It is quite common to use red lamps to indicate to the highway traffic when the bridge is about to open or is open.

The U. S. Government regulations require that the position of each bridge pier, near a navigable channel, be shown by a red lamp. The regulations also require the position of each span to be indicated by red lamps when closed and green lamps when open. This arrangement indicates to boat operators the position of the channel and condition of the bridge.

VII. CONCLUSIONS

Electrical equipments for movable bridges are convenient and economical if properly designed.

Care is necessary in order to so arrange an equipment that it can be operated by low priced operators, who often are not electricians. The equipment for the Lake Street Bridge in Chicago included twenty motors, besides the lighting, indicating, and interlocking circuits, which can be operated from either of two line connections. Name plates are used freely to indicate the use of each device and the wires are marked with circuit numbers so tracing can be done easily.

Electrical equipments can be adapted to quite severe requirements and give satisfaction, but it is poor engineering in a broad sense to make the conditions more severe than would be necessary if the electrical end were given proper consideration in the design.

Dry cotton should not be used to insulate motors or brake coils.

All important units should be duplicated, as the best of electrical apparatus may need repairs some time. This is especially important when conditions may require instant service at any time.

Storage battery charging sets can be so designed, that they will not be seriously overloaded, if charging is continued while the bridge is being operated.

The electrical equipments are installed in rather inaccessible places while heavy bridge members are being handled by all forms of erection equipment; but the writer has never heard of an electrician being injured.

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5. Railway Electrical Engineer, Vol. 2, No.5, p.120, 1910, Electrical Operation of Draw Bridges, S.F.Nichols.
6. Railway Electrical Engineer, Vol. 6, No.10, p.302, 1915, Large Lift Bridge operated by Remote Control, Ed.
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BRIDGE OWNED BY

PORTLAND AND SEATTLE RAILWAY AT VANCOUVER.

The first large bridge to be operated by slip-ring motors.

Energy is supplied for ordinary operation from a 10,000 volt, 3 phase, 33 cycle transmission line. An emergency set is mounted on the span, consisting of a 125 h.p. gasoline engine geared to a 33 cycle generator.

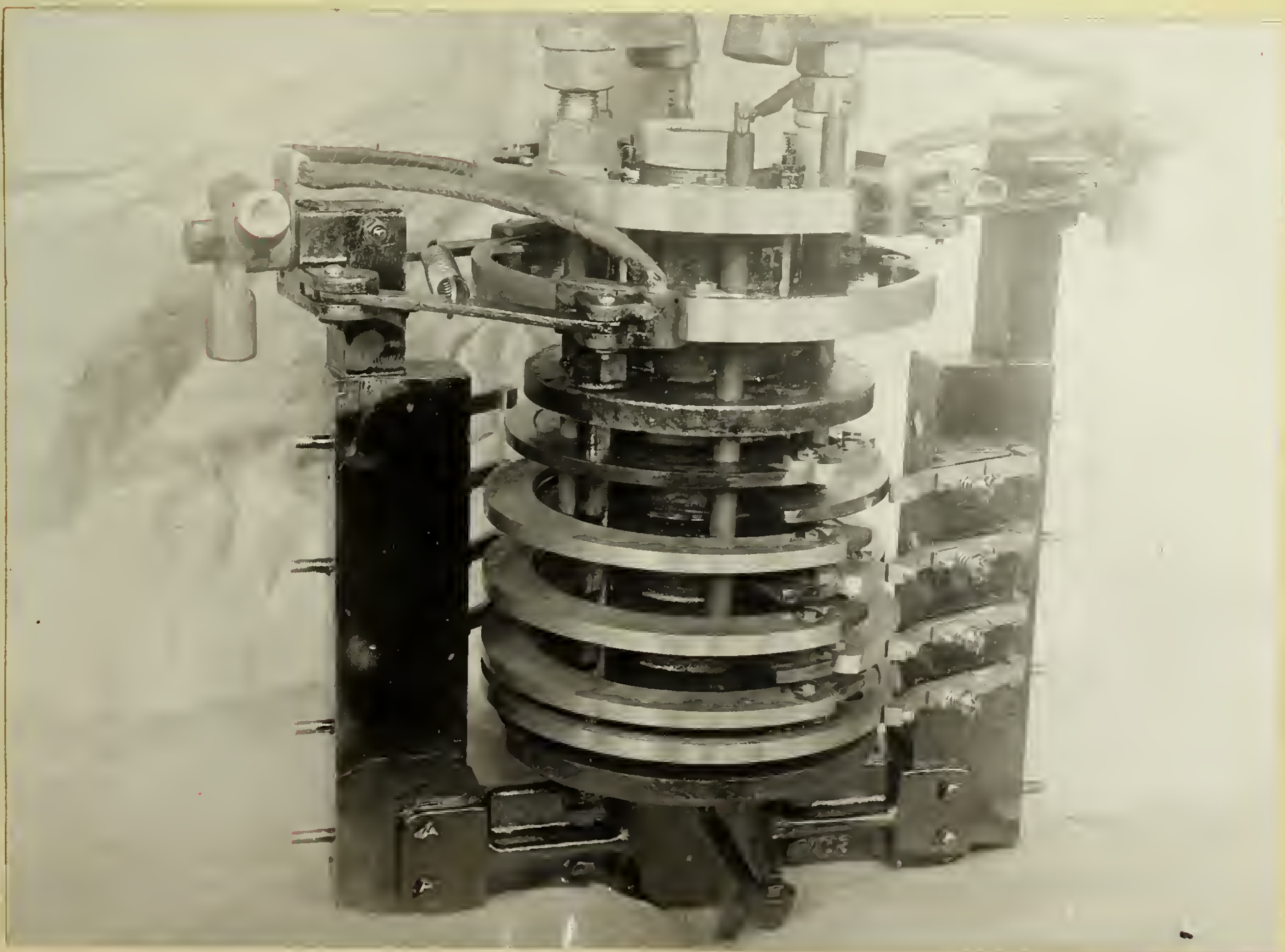
ILLINOIS CENTRAL BRIDGE OVER THE MISSOURI RIVER AT OMAHA.

Two electrically operated swing spans, each 520 feet long, are required end to end at this point on account of the shifting tendency of the river. This span was installed in 1905 and was the first bridge to be completely interlocked.

CENTER COLLECTOR FOR SWING BRIDGE.

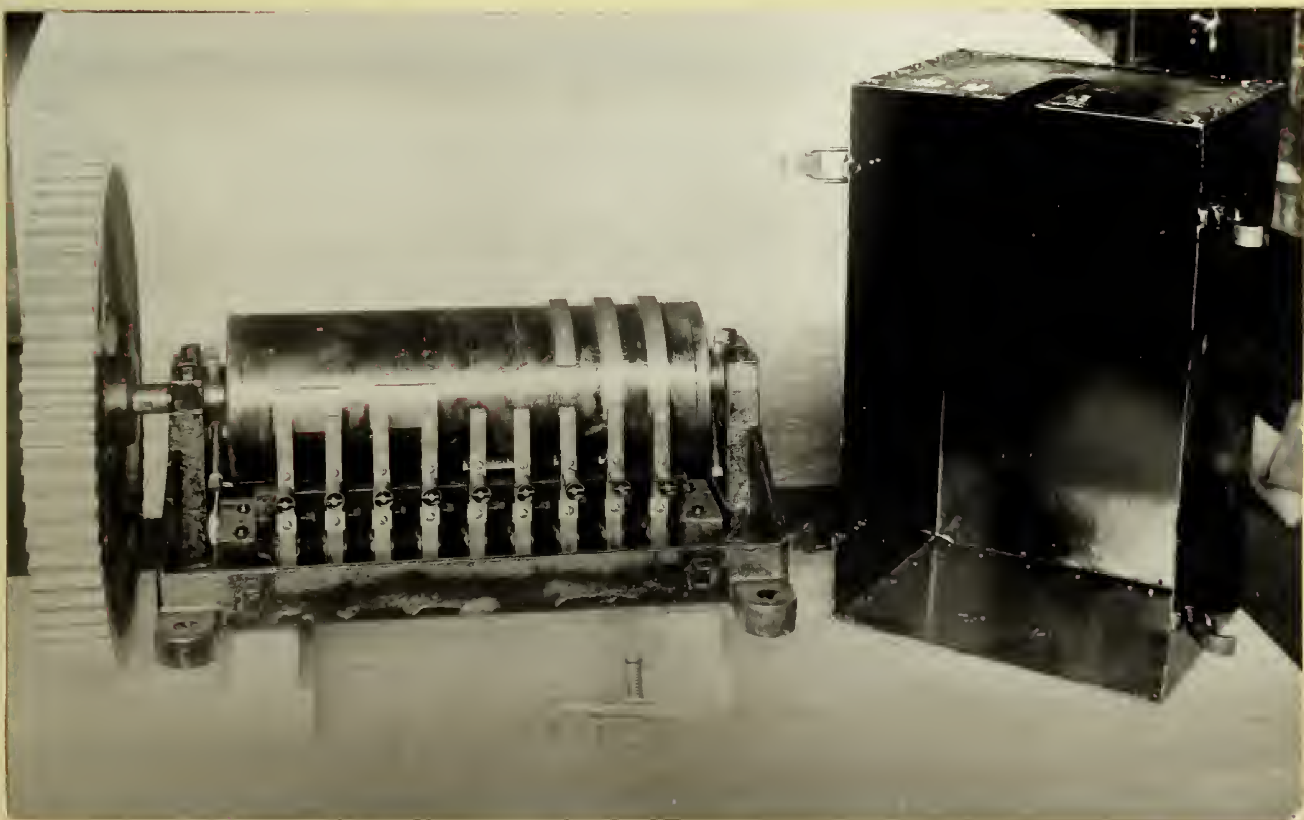
This collector is combined with the span indicator switch. The collector uses the two top rings and transfers the current from the center pier to the bridge span,

This is an example of special design required in equipping movable bridges.



TYPE OF GEARED SWITCH.

Switches of this type are used to stop motors automatically, to operate indicator lamps, and control interlocking circuits. The cover is shown at the right and a separate finger is shown below.

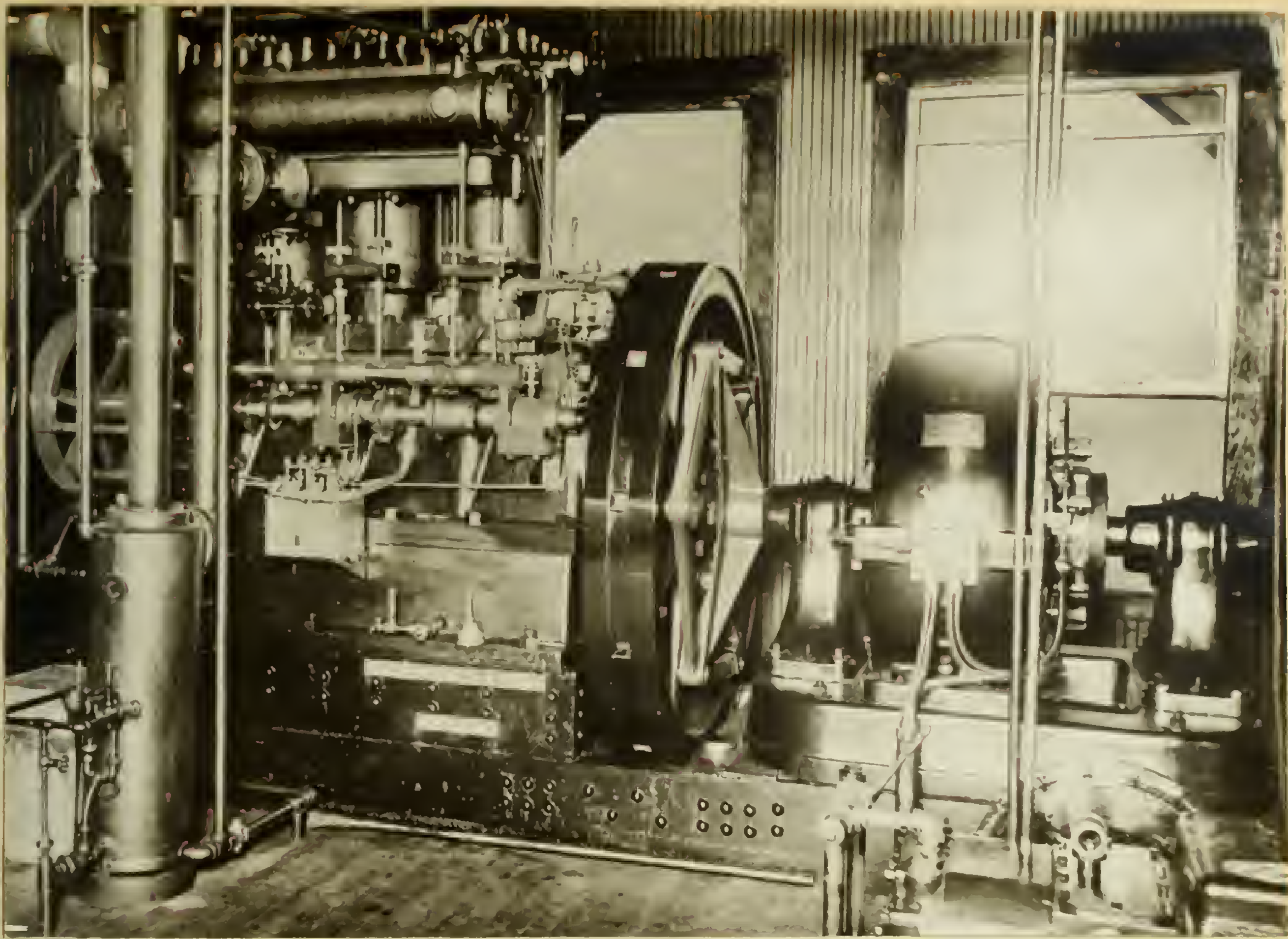


NORTHERN PACIFIC BRIDGE AT DULUTH.

This is an early example of storage battery plant charged by gasoline engines. The lower floor of the house contains two generators while the upper floor contains the battery. A second bridge with similar equipment can be seen in the distance. The two spans were inter-connected by means of a submarine cable.

BOX FOR INDICATOR LAMPS.

Metal boxes surrounding the lamps and mounted on the backs of controllers are necessary to prevent blinding of the operator at night. Small colored glass lenses over the lamps give the operator the signal.



GASOLINE ENGINE AND GENERATOR.

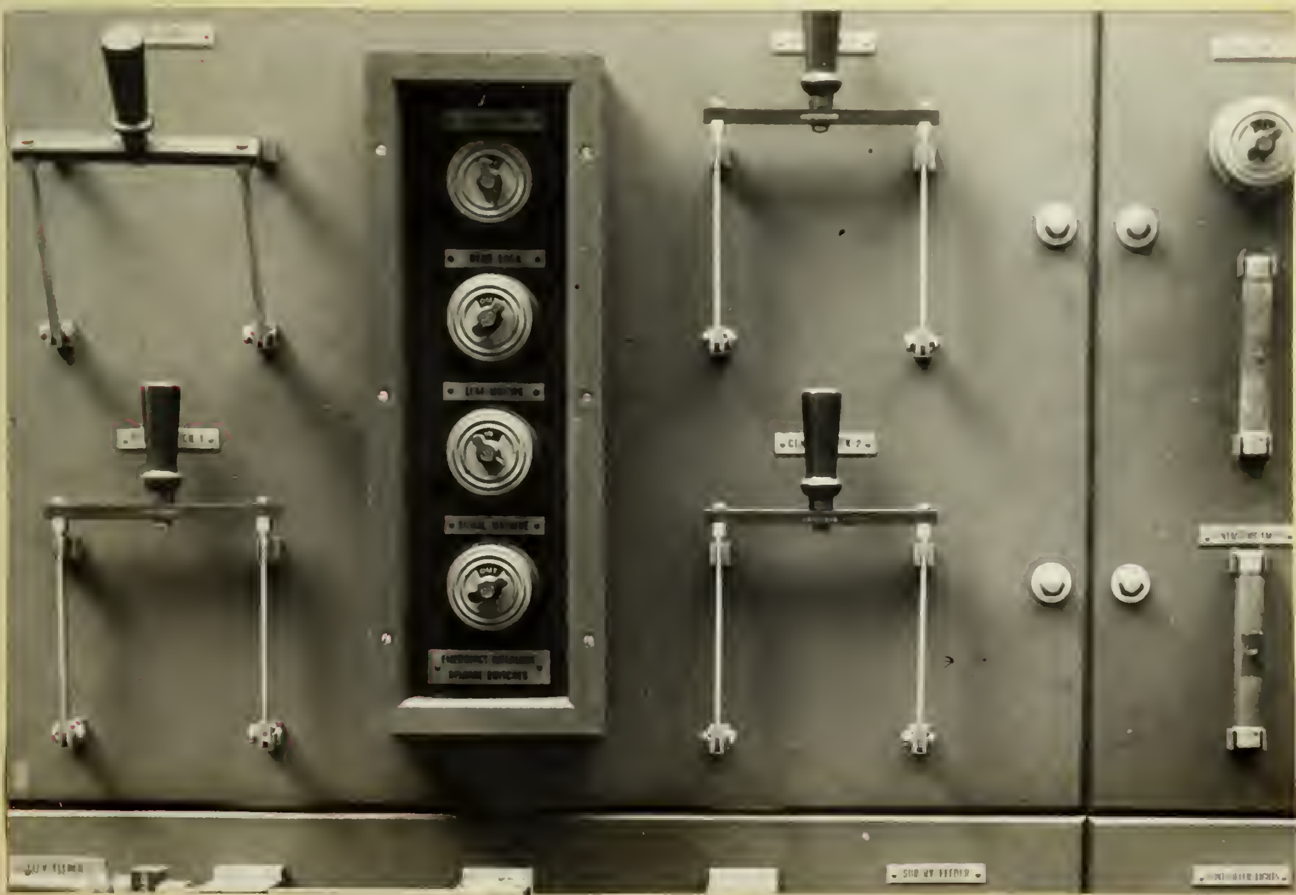
One of the units used by the Northern Pacific Ry. at Duluth. The engines are started by the storage battery using the generator as a motor.

A motor-driven air pump is shown in the lower right hand corner. Compressed air is used for brakes, whistle, and for raising gasoline and water.

INTERLOCKING RELEASE SWITCHES IN GLASS CASE.

In case of irregularities in operation it is sometimes necessary to operate without regard to the interlocking. This should be done only in extreme emergency in which case the operator must break the glass to reach the switches.

This view shows the name plates used to mark all devices.



PENNSYLVANIA BRIDGE OVER CHICAGO RIVER AT EIGHTEENTH ST. CHICAGO

Also used by the Chicago & Alton Ry.

The span is raised by two 325 horse power motors; the largest in use on a drawbridge.

Power is supplied by Commonwealth Edison Co. to charge a storage battery which in turn supplies the bridge. Operating current ranges from 750 to 3000 amperes at 250 volts.

TROLLEY FOR VERTICAL LIFT BRIDGE.

This form of trolley transfers current from the stationary towers to the lifting span.

An example of special design required in bridge work.

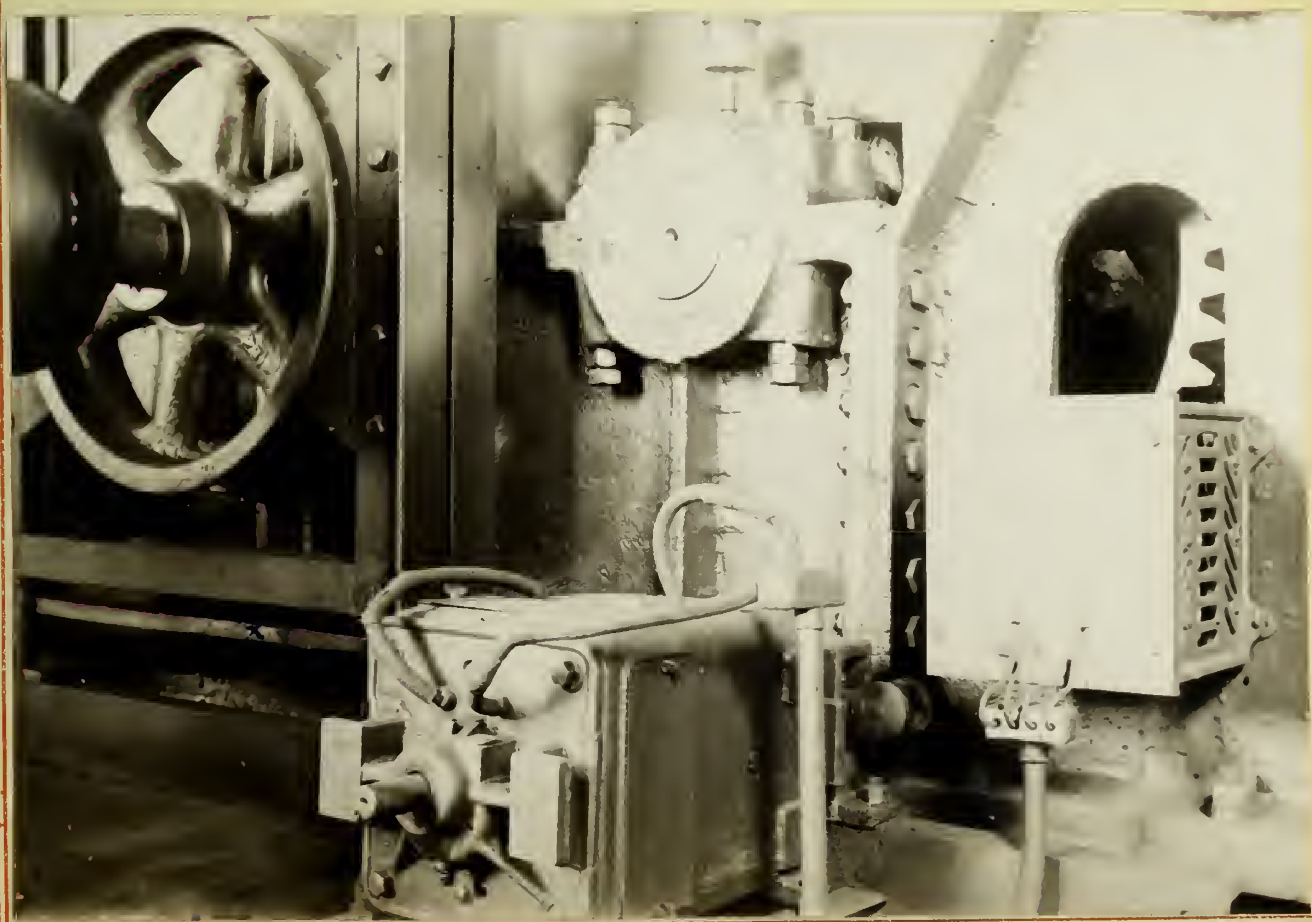
INTERSTATE TRANSFER BRIDGE AT NEW DULUTH, MINN.

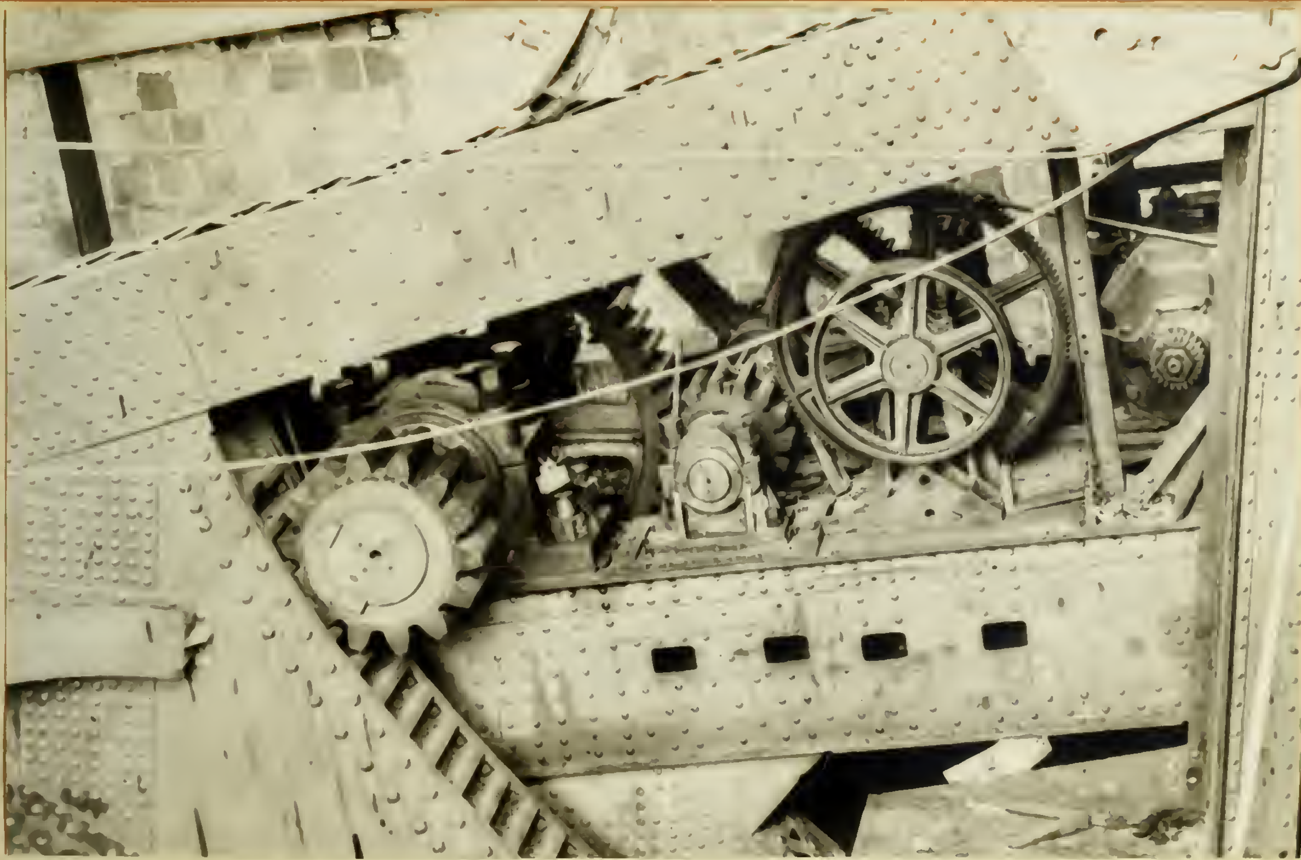
This swing bridge has two decks with two tracks on each deck. The operator's house is in the top of tower at the left hand side. A storage battery and two gasoline-generator sets are located on the lower floor of the building.

MOTOR OPERATED BRAKE

The motor pinion engages the rack bar, marked with a cross, which is connected by levers to two brake shoes bearing on wheel shown at left hand side.

The motor-controlling resistance is shown at the right. Several degrees of retarding torque are possible with this brake.





LEAF MACHINERY ON THE LAKE STREET BRIDGE AT CHICAGO

Two similar sets of machinery with 100 h.p. motors are used to operate each leaf. This view was taken during construction before the motor pinion was meshed with the motor gear. The large pinion meshes with a segmental gear which is built into the movable portion of the bridge.

REAR LOCK MACHINERY ON THE LAKE STREET BRIDGE AT CHICAGO

This machine is used to lock the bridge in the closed position. The locking bar is shown at the right hand edge marked with a cross.

The operating motors are in duplicate.